

REPORT DOCUMENTATION PAGE

OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) 02/26/2010		2. REPORT TYPE Final		3. DATES COVERED (From - To) 06/01/2006 thru 11/30/2009	
4. TITLE AND SUBTITLE Novel Flexible Plastic-Based Solar Cells				5a. CONTRACT NUMBER FA95500610398	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Prasad, Paras N. Cartwright, Alexander N.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University at Buffalo Natural Science Complex North Campus Amherst, NY 14260				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research Foundation of SUNY P.O. Box 9 Albany, NY 12201-0009				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER AFRL-OSR-VA-TR-2013-0921	
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution A: Approved for public release					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT During the three years of this program substantial progress was made with regard to charge extraction and transport in hybrid nanoparticle:polymer photovoltaic devices. In particular, we demonstrated (i) enhancement of charge transport and extraction in nanoparticle:polymer devices by modification of the conductive elements and by modification of nanocrystal ligands; (ii) multiexciton generation and extraction from a photoconductor of PbSe nanoparticles, (iii) hybrid photovoltaic devices consisting of a photoconductor and an organic solar cell, (iv) a photopatternable nanoparticle system that can be used to fabricate heterojunctions of nanocrystal based devices from solution, (v) several types of low bandgap polymers for IR sensitization and (vi) quantum dot sensitized solar cell and hybrid thin film solar cell using in-situ growth method on porous TiO ₂ platform.					
15. SUBJECT TERMS Photovoltaics, Photodetectors, Multiexciton Generation, Polymeric Nanocomposites. Low bandgap polymer					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)

Final Report

(11/30/09)

Prime Contract: FA95500610398
Subcontract: 40216-1-1056694

Novel Flexible Plastic-Based Solar Cells

20130919066

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Institute for Lasers, Photonics and Biophotonics
State University of New York at Buffalo

Final Report in Photovoltaics Project

Multiple research sub-projects are being conducted as follows:

1. Enhancement of Photovoltaic Performance in Polymeric Nanocomposite by Pentacene :

An infrared active thin film polymeric photovoltaic device was fabricated from a regioregular polymer P3HT, PbSe quantum dots and organic semiconductor pentacene. The PbSe quantum dots served as infrared photosensitizers. Pentacene was incorporated into the formulation in a soluble precursor form. The current voltage measurements of the device show that the photovoltaic performance was significantly increased by the introduction of pentacene, with both short circuit current density and open circuit voltage increased by a factor of two. The improved performance of the device was attributed to the high mobility of charge carriers in pentacene probably due to conducting domains provided by it.

2. Multi-Exciton Generation (MEG) in Devices:

We have demonstrated multiple exciton generation and electrical extraction from PbSe nanocrystal quantum dots. Specifically, a quasi tandem structured device was fabricated. This tandem structured demonstrated carrier multiplication in the UV. The tandem structure consisted of a PbSe NQD photoconductor and P3HT/PCBM polymer cell as shown in the figure below. The lower polymer cell supplies an electric field to extract carriers from the PbSe photoconductor when the device is illuminated. By using light bias spectral response measurements, the extracted carriers were measured as a function of wavelength and enhanced extraction due to carrier multiplication was demonstrated in the UV (as seen on the right side of the Figure 1 below).

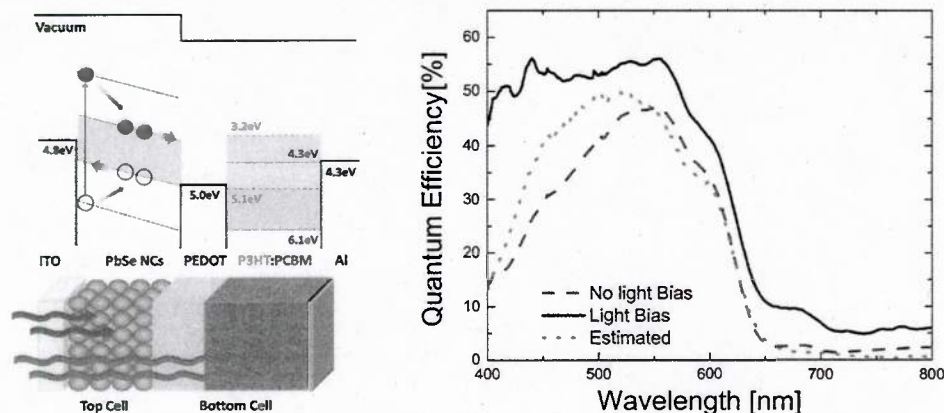


Figure 1: (left) Hybrid tandem photovoltaic cell and band structure alignment and (right) increase in UV response due to the PbSe layer.

3. Self-passivating tandem solar cell using PbSe NQDs and a polymer:

Hybrid tandem structured devices can potentially provide a route for the fabrication of robust solution processed solar cells. In this case, a PbSe nanocrystal layer was deposited on top of an optimized organic solar cell. The PbSe NQD layer has a high absorption coefficient in UV wavelengths. The absorption of the UV by the PbSe cell protects the underlying polymer cell. This hybrid solar cell shows better performance after several hours of UV irradiation when compared to a polymer only solar cell (see Figure 2 below).

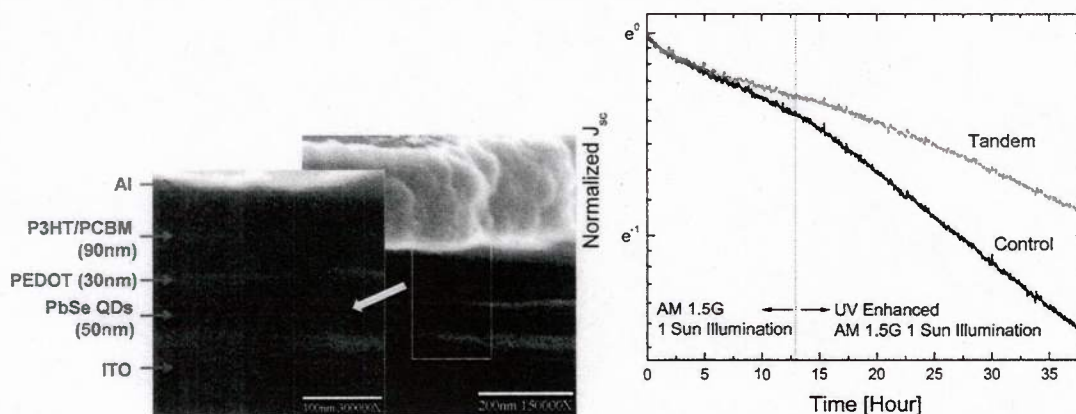


Figure 2: (left) SEM of the hybrid tandem photovoltaic cell with demonstrated improvement in UV performance (right).

4. Direct UV patterning using nanocrystal quantum dots:

A novel nanocrystal patterning method using functionalized ligands on nanocrystals has been developed and successfully demonstrated. This work was the first report of direct UV patterning of NQDs and the ligands (t-BOC protected) show universal applicability to any type of NQDs (including multipods, nanowire, and even larger micron scale particles). The t-BOC deprotection method enables direct photopatterning with a photo acid generator (PAG) and different solvents for the developer. The resulting functionalized ligand system shows enhanced conductivity after deprotection (see examples in figure below).

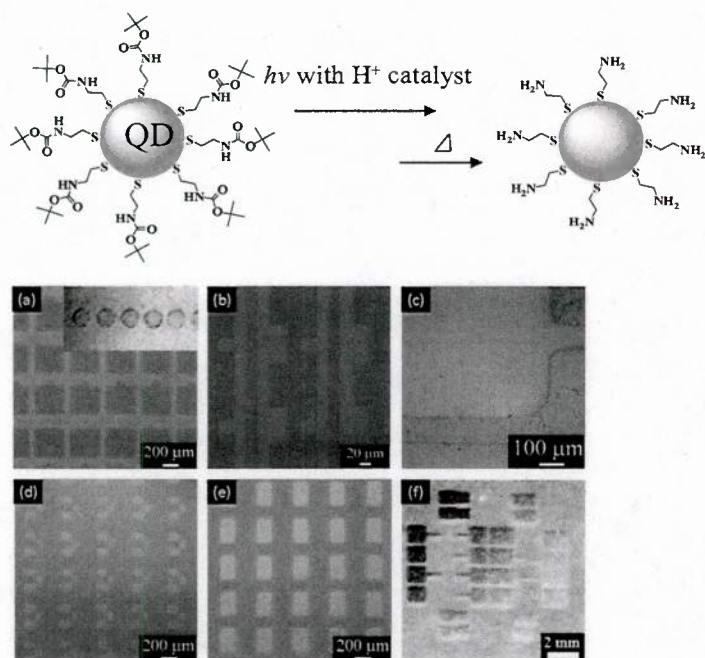


Figure 3: (top) Schematic of cleaving of the *t*-BOC ligand and (bottom) the negative patterned structures using (a) CdTe NQDs, (b) CdTe nanocrystal tripods, (d) CdSe NQDs, (e) CdSe nanocrystal tripods, (f) PbSe NQDs and the positive patterned structure (c) using CdTe NQDs.

5. Nanopatterning using nanocrystal quantum dots and electron beam lithography:

The previous micro patterning work was extended to make higher resolution fine nanopatterns using electron beam lithography (EBL). The *t*-BOC protected functionalized nanocrystals were used for this demonstration. The accelerated electrons hit the nanocrystal surfaces and transfer their energy to break the *t*-BOC protection. Using this strategy, it is possible to obtain nanopatterning capability in the solution without photoacid generator (PAG). This means that the energy from the electrons are used to break the fragile *t*-BOC protection. However, by adding PAG to the nanocrystal solution, we observed even better performance. In this later case, the excess energy was used to activate the PAG and the generated protons initiate the UV patterning. We optimized the lithography conditions including i) dose of electron beam, ii) post baking conditions and iii) developing methods for CdSe *t*-BOC protected nanocrystal quantum dots. To date, 100nm nanopatterns were obtained using this method. We expect this technique can eventually be used to create nanostructured photovoltaic devices.

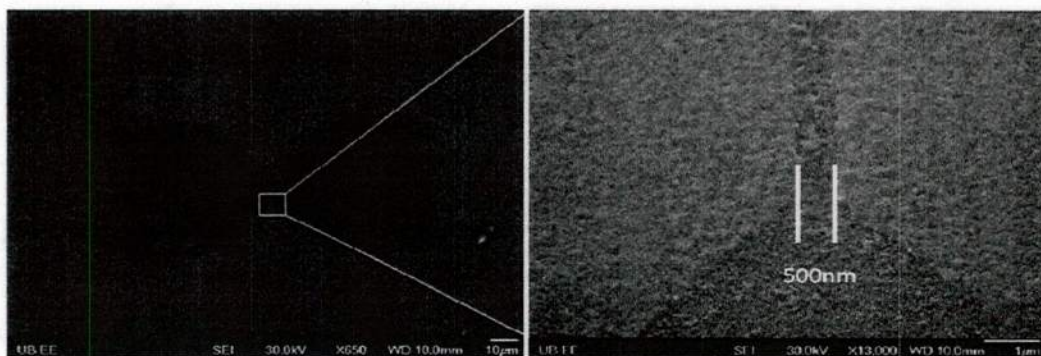


Figure 4: QD nanopattern using electron beam lithography. The dark area on the picture on the left is CdSe nanocrystals and bright area is the Si substrate.

6. NMR Investigation of Ligand Binding on Quantum Dot Surface:

^1H and ^{13}C NMR conducted on ligands such as amines, thiols and carboxylic acid suggest that deprotonation takes place and the ligands bind to the quantum dot surface quasi-covalently. This fundamental knowledge enables possibilities for replacing longer chain ligands with shorter chain or aromatic ones that would facilitate greater charge transfer. This was demonstrated in PbSe films treated with hydrazine to replace the resident oleic acid and results in a three order of magnitude increase in the short circuit current in the photovoltaic device.

7. Post chemical treatment for ligand modification in a polymer/NQD hybrid solar cell

A methodology for the versatile and facile ligand exchange by post fabrication chemical treatment in PbS nanocrystal: poly(3-hexylthiophene) (P3HT) hybrid composite films was demonstrated. We reported considerable improvement of the photovoltaic performance after post chemical treatment using acetic acid to produce PbS nanocrystals surrounded by short-length ligands (representative results are shown on the left of the figure below). Annealing induced morphological and photovoltaic performance changes in the resulting composite films were investigated as a function of the annealing time. In addition, better excitonic interaction for charge generation at the improved interfacial contact in blended film after treatment was confirmed by transient decay of photoluminescence (right side of figure below).

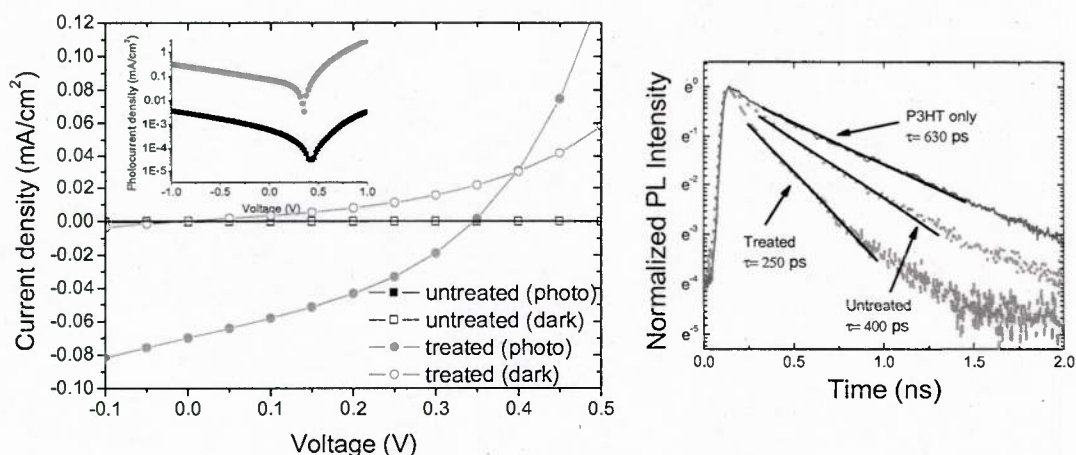


Figure 5: (left) Improved photovoltaic response due to post chemical treatment and (right) time-resolved photoluminescence showing improved charge transfer.

8. CdSe nanocrystal capped with a thermally cleavable solubilizing ligand for a polymer/NQD hybrid solar cell

A relative improvement in hybrid polymer composite photovoltaic cells of P3HT : CdSe nanocrystals was demonstrated by using thermal deprotection processing of *t*BOC in the carbamate ligand surrounding the surface of the CdSe nanocrystal. In a P3HT : CdSe (10 : 90 wt%) device, the short circuit-current density (J_{sc}) was increased by 61 times and the power conversion efficiency (PCE) was enhanced by almost two order of magnitude after the breakage of the *t*Boc group by heat treatment at 200 °C (see graph on left of figure below). The device performance was investigated as a function of the composition ratio of P3HT/ CdSe and the heating temperature (see table on the right of the figure below). This simple and straightforward ligand deprotection strategy resulted in better charge transport between the closer packed nanocrystals as well as improved charge generation. As this processing could endow totally different solubility of nanocrystals before and after the chemical structural change of the ligand on their surface, this thermal deprotection technique of *t*BOC moiety in semiconducting nanocrystals can lead to a facile multilayered device fabrication for further photovoltaic device applications.

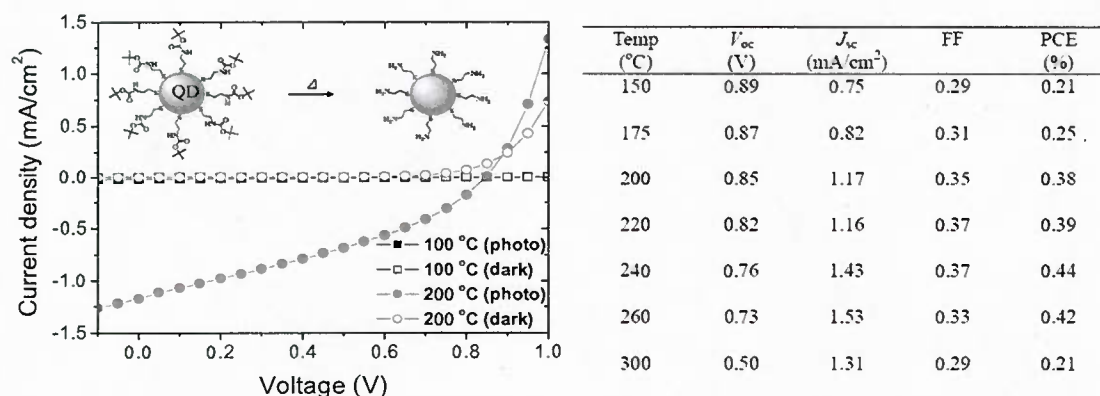


Figure 6: (left) Photovoltaic response due cleaving of the ligand and (right) results from the systematic study of the structures.

9. Synthesis of low bandgap polymers to maximize device efficiency

We synthesized conjugated polymers containing alternating electron-donating and electron-accepting units based on 4,4-bis(2-ethylhexyl)-4*H*-cyclopenta[2,1-*b*:3,4-*b'*]dithiophene(CPDT), 4,7-(2,1,3)-benzothiadiazole(BT), and purified by precipitation in methanol and Soxhlet extractions with acetone. The absorption spectra of the polymer were recorded in solution. The absorption peaks were measured at $\lambda_{max} \sim 715$ nm in chloroform and $\lambda_{max} \sim 720$ nm in *ortho*-dichlorobenzene solution. Polymerized material (M_n , 26 kDa) shows nearly identical results for the reported polymerized materials. The absorption peaks of the same polymer (M_n , 28 kDa) were reported at $\lambda_{max} \sim 721$ nm in chloroform and $\lambda_{max} \sim 730$ nm in *ortho*-dichlorobenzene solution, respectively (see reference, C. Soci, I. W. Hwang, D. Moses, Z. Zhu, D. Waller, R. Gaudiana, C. J. Brabec, and A. J. Heeger, "Photoconductivity of a low-bandgap conjugated polymer," *Adv. Funct. Mat.*, 17, 632 (2007)). We expect that the high molecular weight polymer can be obtained by preparative gel-permeation chromatography (GPC) using chlorobenzene as a solvent.

The optical band gap calculated from the onset of the film absorption is 1.40 eV. The electrochemical properties of PCPDTBT were also investigated by cyclic voltammetry(CV). The HOMO energy levels of PCPDTBT were estimated as - 4.96 and -3.60 eV, respectively. The electrochemical band gap (1.36 eV) is somewhat lower than the corresponding optical band gap (4.0 eV). We performed polymerization of the soluble strong donor, cyclopentadithiophene(4*H*-cyclopenta[2,1-*b*:3,4-*b'*]dithiophene(CPDT) with a strong acceptor, 4,8-dithien-2-yl-2,2'-bis[1,2-*c*:4,5-*c'*]bis[1,2,5]thiadiazole (BTh-BBT), *via* Stille methodology, to obtain a near IR

low band gap polymer **P(CPD-BTh-BBT)** that is soluble processable. The polymerization was carried out in toluene at 110 °C for 2 days. The crude polymer was then purified by Soxhlet extraction with acetone and CHCl₃. The CHCl₃ fraction was concentrated under deduced pressure, precipitated into methanol, and collected by filtration yielding a pale yellow solid. The chemical structure of polymer **P(CPD-BTh-BBT)** was confirmed by ¹H-NMR.

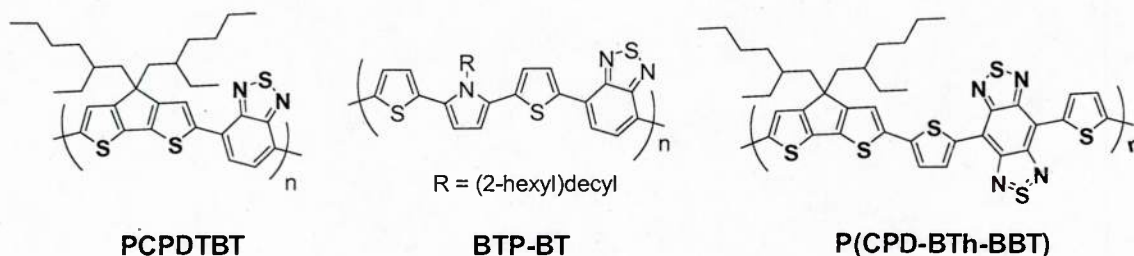


Figure 7: Molecular structure of PCPDTBT, BTP-BT, and P(CPD-BTh-BBT).

Figure 2 shows the normalized UV-Vis absorption of the polymer, **P(CPD-BTh-BBT)** in solution of chlorobenzene (CB) and solid thin film. Two absorption peaks are located at $\lambda \sim 425$ nm and ~ 922 nm in CB solution. The two absorption peaks of polymer in solid thin film are blue- and red- shifted to the absorption peaks measured in CB solution, respectively. The polymer shows extensive light absorption from 610 to 1200 nm in CB solution and 610-1300 nm in solid thin film. A red shift of the absorption peaks of the polymer was observed from solution to solid thin film: this may be indicative of interchain interactions as well as planarization/extension of the conjugated segments occurring in the solid state. The optical band gap of the polymer estimated from the onset of absorption edge ($\lambda = 1240$ nm) in the solid thin film was about 1.0 eV.

The electrochemical properties of **P(CPD-BTh-BBT)** were also investigated by cyclic voltammetry (CV). The onset of oxidation potential of the **P(CPD-BTh-BBT)** is ~ 0.62 eV and the onset of reduction potential is ~ -0.39 eV. The energy level of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of PCPDTBBT can be estimated as -5.33 eV and -4.32 eV from the onset of oxidation wave (E_{ox}) and reduction wave (E_{red}). The electrochemical band gap of **P(CPD-BTh-BBT)** was about 1.01 eV calculated from HOMO and LUMO levels, slightly higher than the optical band gap (1.00 eV). We expect that this polymer can be used as an electron acceptor polymer instead of an electron donor polymer for solution processed polymer-polymer photovoltaic applications.

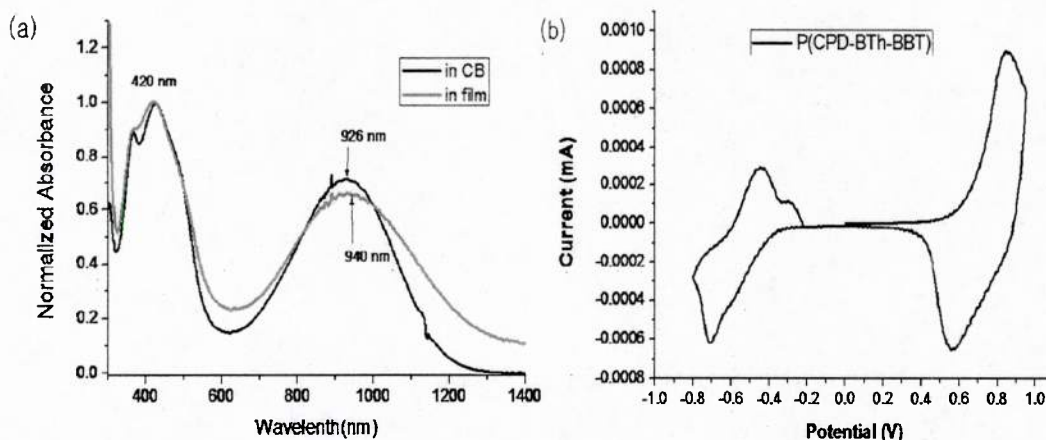


Figure 8. (a) UV-vis absorption spectra of the P(CPD-BTh-BBT) solution in chlorobenzene(CB) and film on a glass plate (b) cyclic voltammogram of the P(CPD-BTh-BBT) film on the platinum plates in an acetonitrile solution of 0.1M $[\text{Bu}_4\text{N}]\text{PF}_6$ (Bu = butyl) with a potential scan rate of 50mV/s

10. Double cable structures – polymer/nanocrystals materials

A novel synthesis of polymers intimately connected to the nanocrystals (NC) has been studied. In this study, a conjugated polymer containing pyrrole will be linked to the nanoparticles, using ligand exchange methodology. For solar cells, this study is highly desirable, because one can integrate electron accepting NCs with electron donating conjugated polymers.

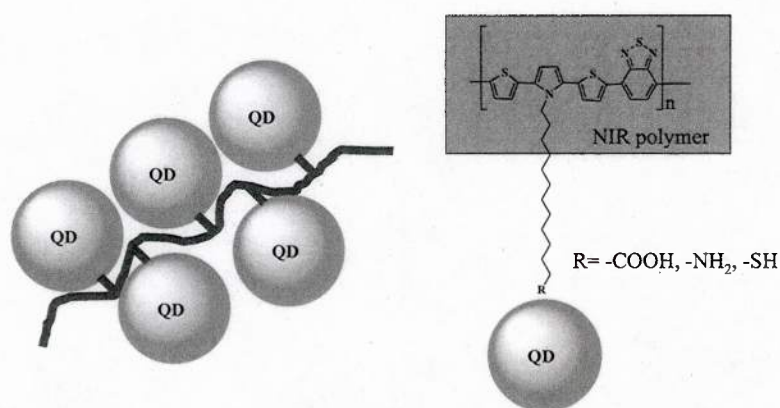


Figure 9: Schematic of QDs connected to the conjugated polymer.

11. QD sensitized solar cell

Dye sensitized solar cells (DSSC) was first demonstrated by M. Gratzel at 1990. Although the DSSC has a very promising structure for a low cost and large area solar panel, the high cost and low extinction coefficient of the dyes are significant obstacles to commercialization of the DSSC. QDs, such as CdS, CdSe, PbS and PbSe etc., are excellent candidates for replacing the dyes because QDs have large extinction coefficient and are easy to fabricate directly on the TiO₂ surface. We have investigated the direct growth of QDs on the TiO₂ matrix. Specifically, CdS and CdSe QDs are created on the TiO₂ nanoparticle matrix using dipping method (*in-situ* growth). Cd and S sources were aqueous solution of Cd(NO₃)₂ and Na₂S, respectively. For the CdSe case, sodium selenosulfate (Na₂SeSO₃) was used as a selenium source for the dipping method. Porous TiO₂, doctor bladed on a FTO coated glass substrate, was immersed in the Cd source for 1 minute and S source for 1 minute at room temperature to create the CdS nanostructures and dipped in the Se source for 1 hour at 50°C to create the CdSe nanostructures. Dipping into a cationic source and anionic source is one full cycle for the QD creation in TiO₂. Incremental increases of absorption at characteristic wavelengths demonstrates that the CdS or CdSe nanoparticles are created on the TiO₂ surface successfully (see left of Figure 10). The red shift of the absorption spectra is indicative of an increase in the particle size as the dipping cycles are increased (see left of Figure 10 below). When the CdSe QDs are created on the CdS QDs layer, the edge of the absorption spectra moves to almost 650nm. This means the CdSe QDs are successfully formed on the CdS QDs layer. I-V characteristic also shows the CdSe contribution on J_{sc} as well as V_{oc}. V_{oc} and J_{sc} are changed from 0.5V to 0.56V and from 4.9mA/cm² to 7.2mA/cm², respectively. Therefore, the power conversion efficiency is increased from 0.97% to 1.5% through the CdSe QDs formation on CdS (see right of Figure 10 below).

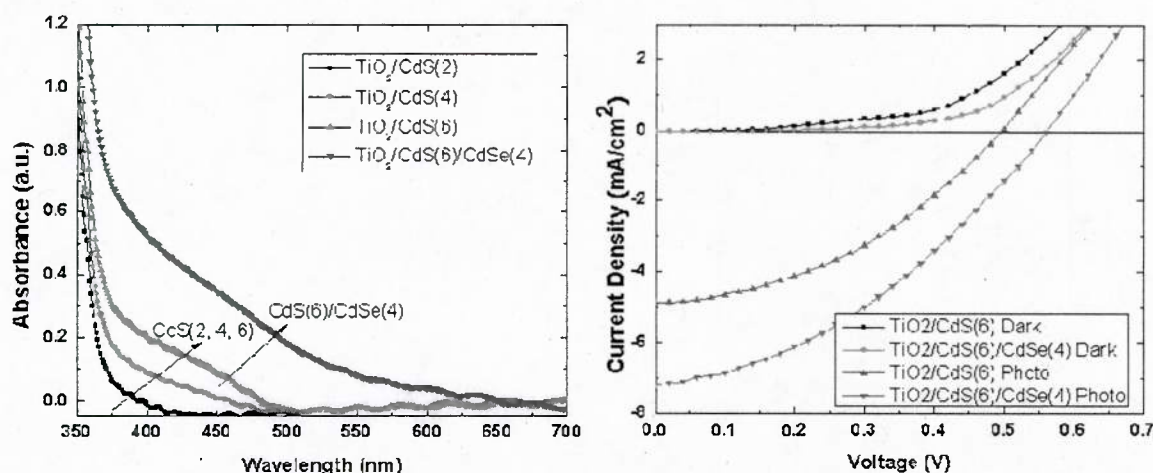


Figure 10: (left) Increases of absorption as a function of dipping cycles and (right) corresponding increases in photovoltaic response.

11. Optimization for CdS/CdSe Quantum Dot co-sensitized solar cell

SILAR based CdS/CdSe QD co-sensitized solar cell is fabricated and the condition for optimum device performance was investigated. The device with single CdS absorber layer shows the best performance at 12 cycles. The CdS/CdSe co-sensitized cell was fabricated with varying the ratio of CdS/CdSe while the total cycle was fixed as 12. The 1:1 ratio (CdS(6)/CdSe(6)) results in the best device performance in terms of PCE(1.55%). Since 12 total cycle may or may not be a optimum condition for best overall performance, we change number of cycles while maintaining a 1:1 ratio of CdS and CdSe. In this case 7 cycles of CdS and CdSe (CdS(7)/CdSe(7)) provided the highest power conversion efficiency with $V_{oc}=0.5V$, $J_{sc}=10.5mA/cm^2$, Fill factor = 44.1% and PCE = 2.57%. Above 17 total cycles, it was found that J_{sc} and V_{oc} drastically decreased. Finally, we performed one more set of optimization test to verify that CdS(7)/CdSe(7) cycle condition was the best for the devices reported here. We increased the number of CdSe cycles while maintaining the number of CdS cycles at 7 (7/5, 7/7, 7/9, 7/11 & 7/13). The resulting I-V curves for these devices are shown in Figure 11. In this case device showed a decrease in photovoltaic performance for all other chosen ratios. Therefore, we determined that the 7/7 ratio of CdS and CdSe was the best number of cycles using

SILAR process in transparent TiO_2 nanostructures with 20~50nm particle size. The inconsistency between short circuit current density (J_{sc}) and the area of external quantum efficiency (EQE) is being investigated with simulating the model including recombination rate, trap density and trapped charge induced electric field.

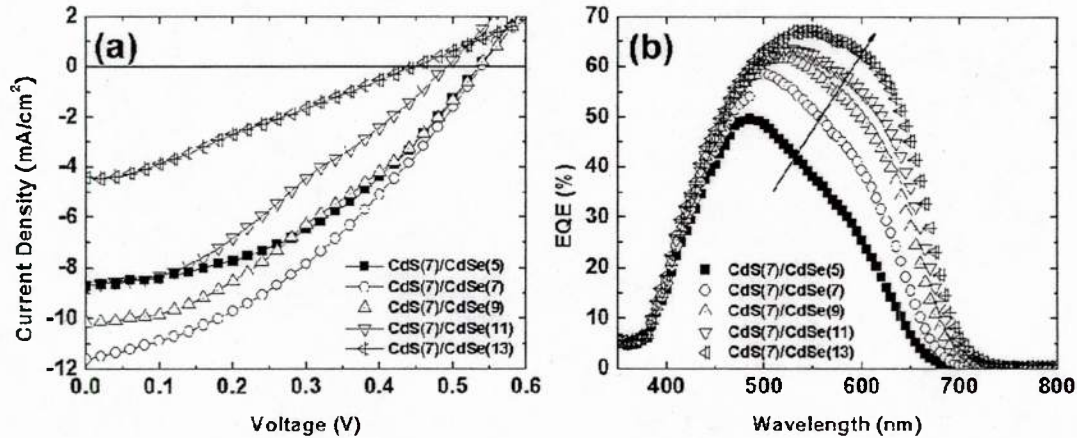


Figure 11 (left) I-V characteristic at different dipping condition and (right) external quantum efficiency results.

12. Solution-based Copper Indium Disulfide solar cell with Spraying method

A low-cost solution based copper indium disulfide solar cell was fabricated by spraying method with DI water precursors. The sample was composed of TiO_2 dense layer, In_2S_3 buffer layer and CIS_2 absorber layer, and all layers were deposited by spray pyrolysis on hot plate. The last polymer blocking layer (PEDOT:PSS) was coated by spin coating at 4000rpm. The growth temperature was 450C for TiO_2 and 300C for both In_2S_3 and CIS_2 layers. The molar ratio of In:S is 1.2:8 for highest photosensitivity and Cu:In:S was 1.2:1:6 for best device performance. The final Au contact was deposited by e-beam evaporation with 50nm. The sample without polymer blocking layer shows 2.37% of PCE with $V_{oc} = 0.4$, $J_{sc} = 16.16 \text{ mA}/\text{cm}^2$, Fill factor = 34.87%. 30% increase of short current density ($J_{sc} = 21.8 \text{ mA}/\text{cm}^2$) and an improved fill factor (36.67%) enhanced the overall power conversion efficiency (3.33%) at polymer coated sample. The thin polymer blocking layer made an effect on reducing the back recombination of excited charges between CIS_2 absorber layer and Au contact.

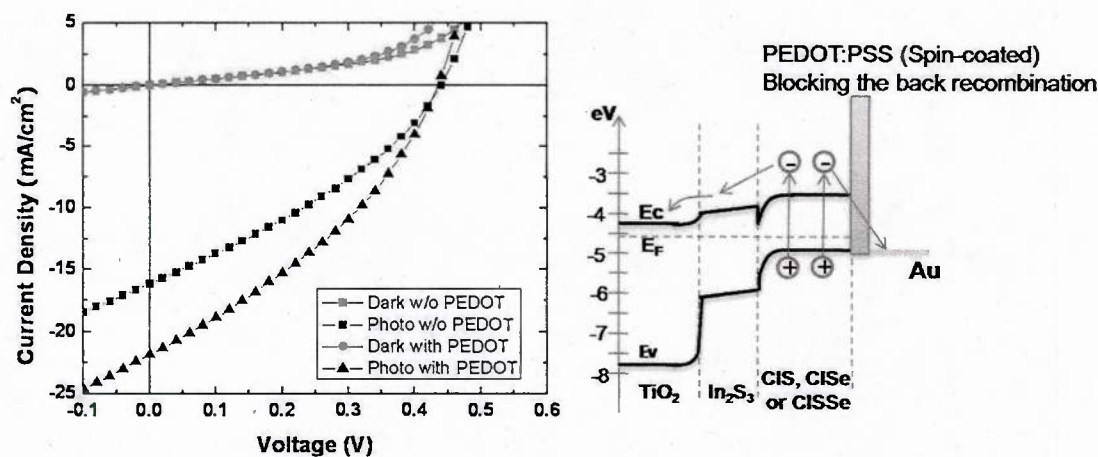


Figure 12 (left) I-V characteristics of sprayed CIS₂ solar cell with and without PEDOT:PSS layer, (right) energy diagram of CIS₂ solar cell with PEDOT:PSS

13. Hybrid photovoltaic device employing PbS nanocrystals and a thin TiO₂ film

We report an efficient hybrid quantum-dot based solar cell with a photoactive medium consisting of multilayers of PbS nanocrystals (NCs) deposited onto a thin nanoporous TiO₂ film on fluorine-doped tin oxide. In this device, layers of PbS NCs were spin-coated onto the TiO₂ film, then treated with 1,2-ethanedithiol. This process yielded layers of NCs embedded within, and capping, the nanoporous TiO₂ film. A hybrid photovoltaic device was formed by spin-coating PEDOT on top of the PbS layer, then depositing a Au metal contact. (see Figure 13a) The junction between the PbS NCs and np-TiO₂ promoted efficient charge separation, which was confirmed by the time-resolved photoluminescence decay of the PbS NCs and PbS-TiO₂ composite dispersed in tetrachloroethylene (TCE) as shown in Figure 11b. Dissociated excitons were transported toward the external electrodes through the layers of PbS NCs (holes) and the TiO₂ film (electrons). The insertion of PEDOT as an electron-blocking layer between the PbS layer and the Au contact resulted in a significant increase in current density, due to the reduction of recombination at the direct contact of the semiconductor and metal. The schematic energy band diagram of this device configuration was described in Figure 11c. As a result, the best-performing device yielded $J_{sc} = 21.5 \text{ mA/cm}^2$, $V_{oc} = 0.34$, $FF = 0.36$ and $PCE = 2.6 \%$ under AM1.5G (100 mW/cm²) illumination. (see Figure 13d) We demonstrate that the open circuit voltage of the device could be tuned by using PbS NCs with different optical bandgaps. Furthermore, we present the impact of PEDOT layer, and the total thickness of the PbS nanocrystal layers, on photovoltaic performance.

Notably, the charge-transport mechanism of the device differs from that of quantum dot-sensitized solar cells, in that photogenerated holes are transported to the cathode via layers of PbS NCs, rather than through a redox-active electrolyte. With continued optimization of power conversion efficiency, this new device architecture may represent an attractive alternative to quantum dot-sensitized solar cells or Schottky junction solar cells.

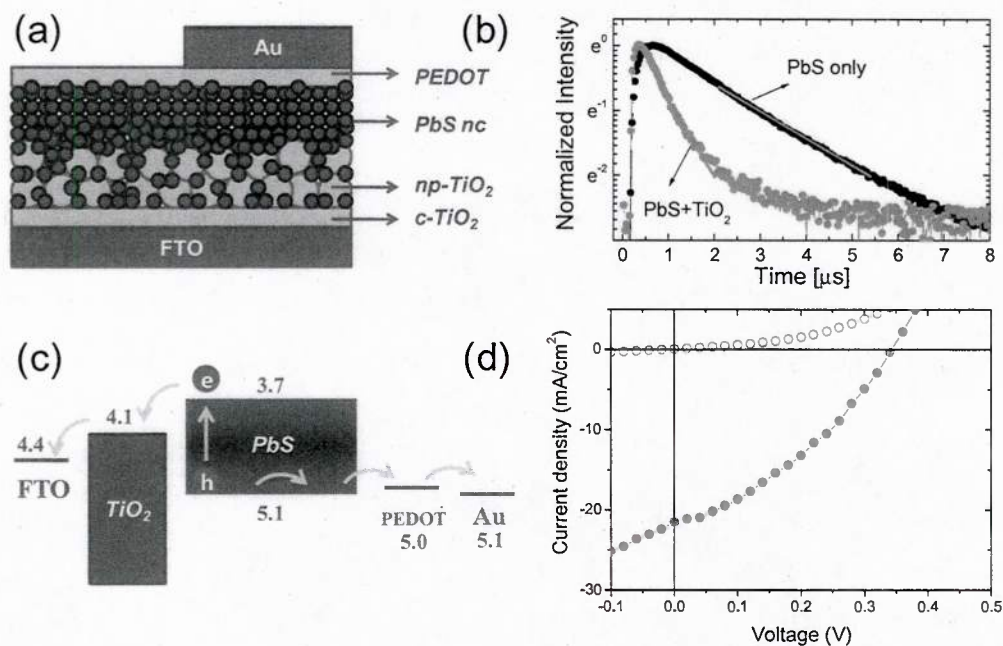


Figure 13: (a) The schematic of the device structure. (b) Time-resolved photoluminescence decay of the PbS NCs (black) and PbS-TiO₂ composite (red) in TCE for PbS NCs. (c) The schematic energy band diagram of FTO/TiO₂/PbS NC/PEDOT/Au. (d) Current-voltage (J-V) curve of a representative device in the dark and under AM1.5G (100 mW/cm²) condition.

Publications:

JOURNAL PAPERS:

1. Sung Jin Kim, Won Jin Kim, Alexander N. Cartwright and Paras N. Prasad, "Self passivating tandem structure solar cell using PbSe Photoconductor and Polymer Cell", *Solar Energy Materials and Solar Cell*, 93, 657-66 (2009)
2. Jangwon Seo, Sung Jin Kim, Won Jin Kim, Rohit Singh, Marek Samoc, Alexander Cartwright and Paras Prasad, "Enhancement of photovoltaic performance in PbS nanocrystal: poly (3-hexylthiophene) hybrid composites by post treatment-driven ligand exchange", *Nanotechnology*, 20, 095202, (2009)
3. Jangwon Seo, Won Jin Kim, Sung Jin Kim, Kwang-Sup Lee, Alexander Cartwright and Paras Prasad, "Polymer nanocomposite photovoltaics utilizing CdSe nanocrystals capped with a thermally cleavable solubilizing ligand", *Appl. Phys. Lett.*, 94, 133302, (2009)

4. Won Jin Kim, Sung Jin Kim, Kwang-Sup Lee, Alexander N. Cartwright, and Paras N. Prasad, "Robust microstructures using UV photopatternable semiconductor nanocrystals", *Nano Lett.*, 8(10), 3262 (2008)
5. Sung Jin Kim, Won Jin Kim, Yudhisthira Sahoo, Alexander N. Cartwright and Paras N. Prasad, "Multiple Exciton Generation and electrical extraction from a PbSe quantum dot photoconductor", *Appl. Phys. Lett.*, 92, 031107, (2008)
6. S.-J. Kim, W.-J. Kim, A.N. Cartwright, and P.N. Prasad, "Carrier Multiplication in a PbSe Nanocrystal and P3HT/PCBM Tandem Cell," *Applied Physics Letters*, 92, 191107 (2008).
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CONFERENCE PROCEEDINGS AND PRESENTATIONS:

1. Sung Jin Kim, Teng-Yin Lin, Alexander N. Cartwright, and Paras N. Prasad, "Direct electron beam nanopatterning using functionalized semiconductor nanocrystal quantum dots ", (2009 MRS Fall Meeting, poster presentation)
2. Dongho Lee, Jeremy S. Nevins, David F. Watson, Alexander N. Cartwright, and Paras N. Prasad, "Tuning of Absorbance Spectra in CdS/CdSe Quantum Dot Co-sensitized solar cell", (MRS Fall Meeting 2009, poster presentation)
3. Won Jin Kim, Sung Jin Kim, Jangwon Seo, Marek Samoc, Yudhisthira Sahoo, Alexander N. Cartwright and Paras N. Prasad, "Binding Characteristics of Surface Ligands on PbSe QDs and Impact on Conductivity", Mater. Res. Soc. Symp. Proc. Vol. 1113 F3-09, 2008 (Poster Presentation)
4. Sung Jin Kim, Won Jin Kim, Jang-won Seo, Alexander N. Cartwright and Paras N. Prasad, " Functionalized semiconductor nanocrystal quantum dots for patterned, multilayered photovoltaic devices", Mater. Res. Soc. Symp. Proc. Vol. 1121, N04-04, 2008, (Oral presentation)
5. Won Jin Kim, Sung Jin Kim, Marek Samoc, Alexander N. Cartwright, and Paras N. Prasad, 'Microfabrication using UV Photo-patternable Semiconductor Nanocrystals' (MRS Fall Meeting 2008, Oral presentation)
6. Sung Jin Kim, Won Jin Kim, Alexander N. Cartwright and Paras N. Prasad, " Tandem inorganic/organic hybrid solar cell using a PbSe nanocrystal photoconductor for carrier multiplication", SPIE Optics+Photonics, San Diego, 2008 (Proc. SPIE 7042, 704222 (2008), Oral presentation)
7. Sung Jin Kim, Won Jin Kim, Alexander N. Cartwright, Ryne P. Raffaele and Paras N. Prasad, "Self Passivating Hybrid (Organic/Inorganic) Tandem Solar Cell", 33rd IEEE Photovoltaic Specialists Conference (May 2008, Late News presentation, San Diego)
8. Sung Jin Kim, Won Jin Kim, Yudhisthira Sahoo, Alexander N. Cartwright and Paras N. Prasad, " Multiple Exciton Generation and Extraction from Hydrazine Treated PbSe Thin Film Device", (MRS Fall Meeting 2007, oral presentation)
9. Won Jin Kim, Sung Jin Kim, Marek Samoc, Alexander N. Cartwright and Paras N. Prasad, "Microfabrication using UV Photo-patternable Semiconductor Nanocrystals", (MRS Fall Meeting 2008, oral presentation)

PATENT DISCLOSURES:

1. "Self Passivating hybrid (Inorganic/Organic) solar cell structure", Sung Jin Kim, Alexander N. Cartwright, Won Jin Kim, and Paras N. Prasad (Patent disclosure filed)
2. "Photo-patternable nanocrystal quantum dots using lithography technique", Won Jin Kim, Sung Jin Kim, Alexander N. Cartwright, and Paras N. Prasad (Patent disclosure filed)

INVITED TALKS:

1. A. N. Cartwright, "Development of Novel Flexible Nanostructured Solar Cells," American Solar Energy Society National Solar Conference, Buffalo, NY, 11-16 May, 2009.
2. A. N. Cartwright, S-J. Kim, W-J. Kim, J. W. Seo, F. Erogbogbo, M. T. Swihart, and P.N. Prasad, "Photopatterned Semiconductor Nanocrystal Films for Photovoltaics," paper O1.3, Materials Research Society Spring Meeting 2009, San Francisco, CA, 10-16 April, 2009.
3. A.N. Cartwright, "Hybrid Inorganic:Organic Photovoltaics," Crossborder Workshop on Laser Science, Cornell University, Ithaca, NY, 16-18 June, 2008.
4. A.N. Cartwright, "Hybrid Inorganic:Organic Photovoltaics," Department of Physics, Rochester Institute of Technology, Rochester, NY, 14 April, 2008.
5. A.N. Cartwright, "Organic and Hybrid Materials and Devices for Energy Harvesting," University of Vermont, Burlington, VT, 18 April 2007.
6. P. N. Prasad, Opening Session Plenary Lecture: "*New Opportunities for Polymers at the Interface of Photonics, Nanotechnology and Biotechnology*" World Polymer Congress, International Union of Pure and Applied Chemistry, Rio, Brazil, July 16-20, 2006.
7. P. N. Prasad, ISBNM International Symposium on Biophotonics, Nanophotonics & Metamaterials, HangZhou, Shanghai and Beijing, China, October 16,18, 2006.
October 16, 2006, Opening Plenary Lecture
October 16, 2006, "*Opportunities in Biophotonics and Nano Photonic*"
October 18, 2006, Tutorial Short Course: "*Opportunities in Nanobiophotonics*"
8. P.N. Prasad, NIST Seminar, "*New Directions for Nanotechnology: Opportunities in Nanophotonics, Nanoplasmonics, Nanomagnetism and Nanomedicine*" Gaithersburg, MD, December 7, 2006.
9. P.N. Prasad, "*New Directions in Photonics: Impact on Energy and 21st Century*" ACS 233rd, Meeting in Chicago, Illinois March 26, 2007
10. P.N. Prasad, Lecture "*New Direction in Photonics: Current and Future Prospects*" South East University, China, June 15, 2007
11. P.N. Prasad, Keynote Lecture "*Nanophotonics: A New Frontier with Multidisciplinary Opportunities and Challenges*" Optical Society of American Topical Conference on Nanophotonics, Hangzhou, China, June 20, 2007
12. P.N. Prasad, Opening Keynote Lecture "*New Directions in Photonics: Impact on Energy and 21st Century Healthcare*" Third International Workshop on photonic and Electronic Materials, San Sebastian, SPAIN, July 4, 2007
13. P.N. Prasad, Opening Keynote Lecture "The Role of Multifunctional Nano-Materials in Biotechnology and Related Industries" International Conference and Workshop on Natural Materials and Fibers, Arad Romania, Oct 8, 2007
14. P.N. Prasad, Opening Key Note Lecture "Nanophotonics: Recent Advances and Future Opportunities" Nanofoton, International Workshop on Nanophotonics, Recife, Brazil, UFPE Jan 14, 2008
15. P.N. Prasad, Keynote Lecture: Nanophotonics, KBI, An International Conference on Knowledge Based Industries and Nanotechnology, DOHA, Qatar. Feb 12, 2008
16. P.N. Prasad, Invited Talk: Multifunctional Nanophotonic and Nanomagnetic Materials for Defense Applications NanoMaterials for Defense Applications Symposium, Crystal City, VA. Parallel Session: "Nanoscience for Photonics and Magnetism" April 23, 2008
17. P.N. Prasad, Opening Keynote Lecture: "*Nanophotonics: A New Frontier with Multidisciplinary Opportunities and Challenges*" International Symposium on Nanophotonics, GuengZhou, China May 23, 2008
18. P.N. Prasad, Opening Keynote Lecture: *Recent Advances, Challenges and Opportunities in Nanophotonics*, Optical Society of America Topical Conference on Nanophotonics, Nanjing China, May 26, 2008
19. P.N. Prasad, "Meeting 21st Century Global Challenges with Novel Multifunctional Nano/BiO Materials" First International Workshop on Advanced Nano-Biomaterials and their Devices Applications, Poiana Brasov, Romania, Sept 18, 2008
20. P.N. Prasad, "*Nanotechnology to Meet the 21st Century Technical Challenges in Healthcare*"

Manila, Philippines, October 27, 2008

21. P.N. Prasad, "*Nanotechnology to Meet the 21st Century Technical Challenges*" KIST- November 13, 2008
22. P.N. Prasad, "*Nanotechnology to Meet the 21st Century Technical Challenges*" Korea University & HanYang University, Daejeon, Korea, November 14, 2008
23. P.N. Prasad, "*Pivotal Role of Photonics in the Nano/Bio/Info Revolution: New Interfaces to meet the challenges of the 21st Century*" HanNam University, and KIRT, Daejeon, Korea, November 17, 2008
24. P.N. Prasad, "*Nanotechnology to Meet the 21st Century Technical Challenges*" International Nanotechnology Forum, Moscow, Russia, December 3, 2008
25. P.N. Prasad, *Invited Talk: "Nanomaterials Based Nanotechnology to Meet the 21st Century Technical Challenges"*, IWAN 2009 Workshop Ras AL Khaimah –Dubai, UAE, February 22, 2009

Personnel Supported:

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